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Study of ultrasonic scattering through non-linearity parameter

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The experimental fact, that the non-linear interaction of two parallel sound beams can produce scattering, has theoretically been established through non-linearity parameter evaluated for higher alkanes namely, nonane and dodecane. The scattered beam pressure increases with temperature while decreases with angular departure, θ.

The deviation from linearity in ordinary acoustics, as observed by Beyer (1960) and Coppens *et al* (1965), is produced by the propogation of high intensity sound wave through fluids. The extent of this non-linearity can be obtained by the parameter (Coppens *et al* 1965) B/A given below

$$\frac{B}{A} = 2\rho_0 C\left(\frac{\partial p}{\partial \rho}\right)_S, \ \rho = \rho_0 \quad \ldots (1)$$

Using some theromodynamic transformations, the above expression may be written as

$$\frac{B}{A} = 2\rho_0 C\left[\left(\frac{\partial C}{\partial P}\right)_T\right]_{\rho=\rho_0} + \frac{2\beta T C}{C_P}\left[\left(\frac{\partial C}{\partial T}\right)_P\right]_{\rho=\rho_0}$$
$$= \left(\frac{B}{A}\right)' + \left(\frac{B}{A}\right)'' . \quad \ldots (2)$$

where ρ_0 is the equilibrium density and other terms have their usual notations. The importance of above parameter B/A lies in explaining the molecular spacing, internal pressure and acoustic scattering. Also it is related to the factor L defined for the distortion of finite amplitude waves in fluids by the expression given below

$$L = 1+(\tfrac{1}{2})\frac{B}{A} \quad \ldots (3)$$

Westervet (1957), in his preliminary studies found no scattering for the orthogonal incidence of two high density collimated beams. But the further results obtained from his (Westervet 1960) experimental study, on the same subject established the significance of above discussed non-linearity by stating that the non-linear interaction of two parallel sound beams can produce scattering. As a consequence of the above study, the acoustic beam pressure of the scattered sound at the point (R, θ) can be given in terms of radial coordinates (R, θ) as follows,

$$P_S = \frac{\omega_S^2 P_0^2 S \beta L}{8\pi R C^2} \cdot \frac{1}{[\alpha^2 + K_S^2 \sin^4(\theta/2)]^{\frac{1}{2}}} \quad \ldots \quad (4)$$

where ω_S is the modulation frequency, P_0 and S are the beam pressure and cross-sectional area of incident beams (equal) β, C and α are adiabatic compressibility, ultrasonic velocity and absorption coefficient respectively for the liquid and $K_S = \omega_S/C$, is the wave number of modulation signal.

Various parameters required is eq (2) have been extracted from the paper of Boelhouwer (1967) The values of $(\partial C/\partial P)_T$, $(\partial C/\partial T)_P$, $(B/A)'$, $(B/A)''$ and B/A computed from these data are shown in table 1 As seen from table 1, the values of B/A for both liquids, nonane and dodecane, decrease with temperature while they increase with the advancement in the homologous series. It is interesting to note that the values of $(B/A)''$ are negative at all the temperatures and very small in comparision to the values of $(B/A)'$ Due to the above facts less accuracy was required for $(\partial C/\partial T)_P$ than for $(\partial C/\partial P)_T$.

Table 1 Primary physical parameters for nonane and dodecane

Parameters	nonane		dodecane	
	at $-20°$C	at $0°$C	at $0°$C	at $20°$C
$\left(\frac{\partial C}{\partial P}\right)_T$ (m/bar)	0.56	0.60	0.58	0.62
$\left(\frac{B}{A}\right)'$	11.68	11.52	12.19	12.04
$\left(\frac{B}{A}\right)''$	-0.18	-0.29	-0.08	-0.03
$\left(\frac{B}{A}\right)$	11.50	11.33	12.11	12.01
	6.75	6.65	7.05	7.00

For the study of scattering, from eq. (4), we have considered the values of various parameters as, $P_0 = 10^5$ dynes/cm^2 $\omega_S = 1$ MHz, $S = 7$ cm^2 and $R = 2$ cm For the absorption of both the liquids, the data of Cochran *et al* (1972) have been used and the values of parameter L are taken from table 1 The variation of normalised scattred beam pressure with angular departure (θ) of the pick up point, for nonane and dodecane have been shown in figure 1 for different temperatures The shapes of these directivity patterns are very similar to those drawn for water experimentally by Bellin *et al* (1962) The most noticeable behaviour is that as temperature increases, patterns tend to become narrower in both the cases of nonane and dodecane. . However, scattered beam pressure is small for high absorption liquid (dodecane) and its increase with temperature in both the cases Moreover, we can draw the conclusion from figure 1 that the scattered beam pressure is maximum for two parallel sound beams (i e , $\theta = 0$) and minimum for two orthogonal beams. This establishes the experimental fact as observed by Westervet (1960)

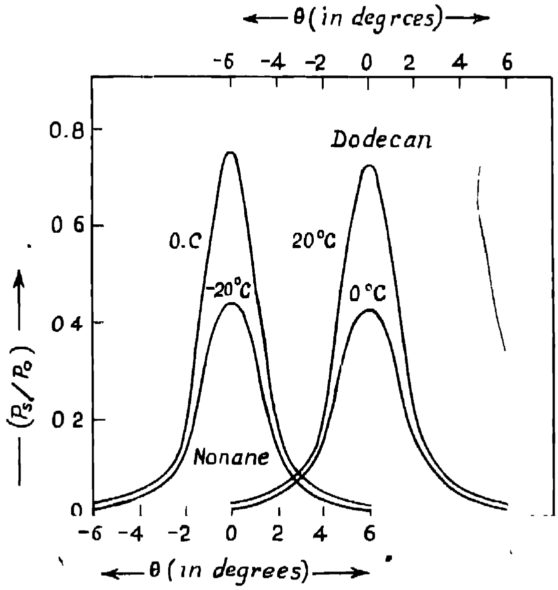

Fig. 1.

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